

VISCOSITY PREDICTION FOR NATURAL GAS MIXTURES

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ABSTRACT

The viscosity of multi-component natural gas mixtures containing hydrocarbons (C1 through C7) is predicted by modifying a previously published dilute gas viscosity model and extending its applicability to a wide range of temperature and pressure conditions including liquid and gas states. Nitrogen, oxygen, carbon dioxide, and helium are also included among components of mixtures for which published viscosity data are available. The approach takes advantage of currently available formulations and models for the density and viscosity of pure fluid constituents of natural gases. The predicted viscosity is compared with available data in both gas and liquid regions. Comparisons of calculated values to the available measurements of viscosity of natural gas mixtures and of binary, ternary, and quaternary mixtures of constituent fluids have been summarized to illustrate the accuracy of the predicted values.

KEYWORD

Viscosity, prediction, natural gas

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1. INTRODUCTION

This paper reports a new development in a series of studies of comprehensive models for transport properties of pure fluids and mixtures covering a wide range of fluid states. The motivation of this study is the need for a model for transport properties to serve as a companion to the generalized mixture model for equilibrium thermodynamic properties reported by Lemmon and Jacobsen [1].

The ultimate goal is a versatile package of computer programs capable of calculating all fluid properties of interest to the design engineer over a wide range of temperatures and pressures including liquid and gas states. The application to natural gas mixtures has been stimulated by the continued increasing demand for natural gas as an energy resource.

One-fluid corresponding states methods are most often used to estimate the viscosity of natural gases. Among the generally accepted methods, reduced viscosity charts [2] have been used by natural gas engineers for several decades. On the charts the ratio of the viscosity of natural gas to its viscosity at the same temperature and at one atmosphere pressure is related to pseudo-reduced temperature and pseudo-reduced pressure of the mixture. The viscosity of gas mixtures at low pressures is obtained from the viscosity of the constituent pure fluids by applying mixing rules. The format of generalized charts is not compatible with modern computer process design and analysis. The Herning and Zipperer [3] mixture viscosity equation has long been used as a mixing rule for dilute gas mixture viscosity. The extended corresponding states (ECS) method [4] assumes the viscosity of a mixture can be treated as that of a pseudo-pure fluid corresponding to a specified state of a selected reference fluid. Shape factors are introduced to modify the behavior of the fluid at the reduced states of the mixture and reference fluid. The ECS method has been used for hydrocarbons, and has been extended to polar refrigerant mixtures. Other attempts to predict the mixture viscosity

over wide ranges of conditions include using equations of state to represent the viscosity of mixtures.

In contrast to the one-fluid corresponding states methods, this paper reports a method for viscosity prediction for natural gases and constituent mixtures based on the viscosity of the pure components.

Herning and Zipperer's dilute gas viscosity equation [3] has been extended to wide temperature and pressure ranges. The viscosity of a mixture is obtained by using Herning and Zipperer's equation with the viscosity of constituent pure fluids at states corresponding to the mixture temperature and pressure. Formulations for the viscosity and density of the pure fluid constituents are required.

Published equations of state for pure fluids are used in this work to calculate the density of the pure fluids at the corresponding temperature and corresponding pressure as defined in the following section. Published formulations from the literature are used for the viscosity of pure methane, ethane, propane, carbon dioxide, nitrogen, helium, and oxygen. The viscosity of pure n-butane, iso-butane, pentane, hexane, and heptane are estimated using a two-reference fluid corresponding states method given by Teja and Rice [5]. The predicted viscosity for natural gases and constituent mixtures is compared with available experimental data in both gas and liquid regions to confirm the accuracy of the calculated values.

A summary of comparisons of viscosity calculated using our approach to available data sets is given.

A brief analysis of the experimental viscosity data for natural gas is also included.

2. VISCOSITY PREDICTION FOR NATURAL GASES AND CONSTITUENT MIXTURES

2.1 Mixing rule for the viscosity of natural gases and constituent mixtures

Herning and Zipperer [3] proposed the following mixing rule for the viscosity of a gaseous mixture at low pressure:

$$\mu_m^0 = \frac{\sum_{i=1}^n x_i \mu_i^0 \sqrt{M_i}}{\sum_{i=1}^n x_i \sqrt{M_i}}, \quad (1)$$

where μ_m^0 is the viscosity of a gaseous mixture at low pressure, μ_i^0 is the viscosity of component i at the pressure and temperature of the mixture, and x_i and M_i are the mole fraction and molar mass of component i , respectively. Equation (1) has been used for viscosity estimation for natural gases at atmospheric pressures by various authors including Carr et al. [6] and Lohrenz et al. [7].

In our present work we extend this simple mixing rule to all temperature and pressure ranges of natural gases for which viscosity data are available from the literature. The viscosity of a natural gas at any temperature and pressure is written as:

$$\mu_m(T, P) = \frac{\sum_{i=1}^n x_i \mu_i(T_i^{cor}, D_i^{cor}) \sqrt{M_i}}{\sum_{i=1}^n x_i \sqrt{M_i}} \quad (2)$$

where $\mu_m(T, P)$ is the mixture viscosity at temperature T and pressure P , $\mu_i(T_i^{cor}, D_i^{cor})$ is the viscosity of pure component i at corresponding temperature T_i^{cor} and corresponding density D_i^{cor} .

The corresponding temperature T_i^{cor} , corresponding density D_i^{cor} , and corresponding pressure P_i^{cor} are given as follows:

$$T_i^{cor} = TT_{c,i} / T_{c,m} \quad (3)$$

$$D_i^{cor} = D_i(T_{c,i}^{cor}, P_{c,i}^{cor}) \quad (4)$$

$$P_i^{cor} = PP_{c,i} / P_{c,m} \quad (5)$$

where $T_{c,i}$ and $P_{c,i}$ are the critical temperature and critical pressure of component i , $T_{c,m}$ and $P_{c,m}$ are the pseudo-critical temperature and pseudo-critical pressure of the mixture, which are obtained using the mixing rules given by Teja and Thurner [8].

To obtain the mixture viscosity at any temperature and any pressure we first calculate the corresponding density D_i^{cor} using an equation of state for each pure component i . Then we use the individual viscosity representation for each pure fluid to obtain the viscosity of that fluid at the corresponding temperature T_i^{cor} and corresponding density D_i^{cor} . The mixture viscosity is then calculated using equation (2) above.

2.2 Density and viscosity formulations for pure components

For most pure components in natural gases, equations for the viscosity dependence on density and temperature and the density dependence on temperature and pressure are available in the literature.

Table 1 lists the sources of the formulations used for calculating the density and the viscosity of pure fluids. Table 2 gives the statistical analysis of the viscosity representations for the pure fluids compared to our collected viscosity data. Table 2 shows that the viscosity formulations for the main components in normal natural gases, e.g., methane, ethane, propane, nitrogen are within 1% of measured values.

3. COMPARISON OF PREDICTED MIXTURE VISCOSITY WITH DATA

3.1 Viscosity data from the literature

There is a paucity of viscosity data available for natural gases in the literature, particularly in the 1980s' and 1990s'. The compositions of the associated natural gases are listed in Table 3, as well as the compositions of other multi-component mixtures. The ranges of pressure, density, temperature, and viscosity for these systems are listed in Table 4. Data on the viscosity of binary mixtures has also been collected from the literature. The data ranges for the binary systems are given in Table 5.

3.2 Comparison results

The predicted mixture viscosities have been compared with the literature data. Tables 4 and 5 show the statistical analysis of the comparisons using the following parameters:

$$\%Dev = 100 \left(\frac{\mu_{Exp} - \mu_{Pred}}{\mu_{Exp}} \right) \quad (6)$$

$$AAD = \frac{1}{n} \sum_{i=1}^n | \%Dev_i | \quad (7)$$

$$Bias = \frac{1}{n} \sum_{i=1}^n (\%Dev_i) \quad (8)$$

$$StdDev = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (\%Dev_i - Bias)^2} \quad (9)$$

$$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^n (\% Dev_i)^2} \quad (10)$$

$$MaxDev = \max\{|\% Dev_i|\} \quad (11)$$

where μ_{Exp} is the experimental viscosity and μ_{Pred} is the predicted viscosity.

The majority of comparisons in Tables 4 and 5 demonstrate that the calculated viscosity of natural gas mixtures is within $\pm 2\%$ of measured values. The comparisons in Tables 4 and 5 also indicate that the uncertainties of calculated viscosities of mixtures containing carbon dioxide and nitrogen are larger than those of other mixtures. These deviations for mixture viscosity may be caused by the relative simplicity of the model and its inability to represent the complex behavior of these mixtures. However, the relatively large deviations of calculated viscosities for pure carbon dioxide from data values, as listed in Table 2, are also a probable cause of inaccuracies in the calculated viscosity for mixtures containing carbon dioxide.

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Table 1. Sources of Viscosity and Density Formulations for Pure Constituents of Natural Gases

Fluid (Synonym)	Source of Density Formulation	Source of Viscosity Formulation
Methane (C1)	Setzmann and Wagner [9]	Friend et al. [17]
Ethane (C2)	Friend et al. [10]	Friend et al. [10]
Propane (C3)	Younglove and Ely [11]	Vogel et al. [18]
n-Butane (C4)	Younglove and Ely [11]	Teja and Rice (C2 and C3 as reference fluids)[5]
i-Butane (iC4)	Younglove and Ely [11]	Teja and Rice (C2 and C3 as reference fluids)[5]
Pentane (C5)	Starling [12]	Teja and Rice (C3 and C4 as reference fluids)[5]
Hexane (C6)	Starling [12]	Teja and Rice (C3 and C4 as reference fluids) [5]
Heptane (C7)	Starling [12]	Teja and Rice (C3 and C4 as reference fluids)[5]
Carbon Dioxide (CO ₂)	Span and Wagner [13]	Fenghour and Wakeham [19]
Nitrogen (N ₂)	Span et al. [14]	Shan et al. [20]
Helium (He)	McCarty and Arp [15]	McCarty [21]
Oxygen (O ₂)	Schmidt and Wagner [16]	Shan et al. [20]

Table 2. Comparison between Viscosity Calculated by Models and Experimental Data for Pure Fluids

Author	No. of Points	AAD	Bias	Std. Dev.	RMS	MaxDev	No of Points Dev> 10%	Ranges of Properties			
								Pressure [MPa]	Density [Mol.dm ⁻³]	Temperature [K]	Viscosity [μPa.s]
Methane											
Huang et al. [22]	114	2.344	0.366	2.877	2.887	9.704	5	0.0 – 35	0.0 - 28.5	103 - 273	5- 206
Boon et al. [23]	8	2.474	-2.256	1.844	2.84	-4.662	0	0.0 - 0.1	26.1 – 28	91 - 114	112 - 200
Giddings et al. [24]	100	0.277	0.089	0.38	0.388	-1.509	0	0.1 – 55	0.0 - 18.5	283 - 411	10.7 - 39
Diller [25]	116	0.964	0.49	1.335	1.417	6.093	0	0.6 - 33	1.0 - 28.6	100 - 300	9 - 219
Carmichael et al. [26]	103	0.727	0.494	0.818	0.952	3.172	0	0.1 – 36	0.0 - 15.9	278 - 478	10.5 - 31
Carr [27]	77	0.996	-0.5	1.07	1.174	-2.676	1	0.1 – 55	0.0 - 17.8	294 - 367	10.8 - 36
Van der Gulik [28]	26	3.022	2.098	2.708	3.376	5.725	4	0.1 – 300	0.0 - 27.7	298 - 298	11 - 116
Overall	544	1.183	0.274	1.749	1.768	9.704	10	0.0 – 300	0.0 - 28.6	91 - 478	5 - 219
Ethane											
Carmichael and Sage[29]	226	0.804	0.05	1.118	1.116	4.5	0	0.1 – 36	0.0 – 15	300 - 478	9.4 - 83.4
Diller and Saber [30]	164	0.845	0.188	1.077	1.09	3.635	0	0.0 – 32	0.3 – 22	95 - 320	9.4 – 1130
Diller and Ely [31]	71	1.066	-0.008	1.393	1.383	5.075	3	1.7 – 61	0.7 – 16	292 - 500	10.4 – 100
Eakin et al. [32]	209	1.545	-0.445	2.188	2.228	-8.855	8	0.1 – 69	0.0 – 17	294 - 511	9 – 111
Kestin et al. [33]	5	1.435	-0.02	1.775	1.588	-2.734	0	0.0	0.0	301 - 477	9 - 15
Overall	675	1.07	-0.072	1.56	1.56	-8.855	11	0.0 – 69	0.0 – 22	95 - 511	9 – 1130
Propane											
Huang et al. [22]	36	0.35	-0.138	0.531	0.541	-1.52	0	0.0 – 35	12.0 – 15	173 - 273	126 – 554
Kestin et al. [34]	5	0.696	0.696	0.352	0.764	0.952	0	0.1	0.0	299 - 478	8 - 12.9
Giddings et al. [25]	78	0.527	0.264	0.813	0.85	-5.413	1	0.1 – 55	0.0 – 13	278 - 378	7 – 186.3
Overall	119	0.481	0.159	0.751	0.765	-5.413	1	0.0 – 55	0.0 – 15	173 - 478	7 – 554
Butane											
Kestin et al. [34]	5	0.427	0.417	0.322	0.507	0.79	0	0.1	0.0	299 - 478	7.5 - 11.8

Author	No. of Points	AAD	Bias	Std. Dev.	RMS	MaxDev	No of Points Dev> 10%	Ranges of Properties			
								Pressure [MPa]	Density [Mol.dm ⁻³]	Temperature [K]	Viscosity [μPa.s]
Carbon Dioxide											
Herreman et al. [34]	111	5.223	5.089	2.272	5.569	9.994	15	1.0 – 19	14.2 – 27	219 - 303	55 – 242
Van Dyke [35]	11	0.844	-0.844	0.048	0.846	-0.918	0	0.1	0.0	296	15
Diller and Ball [36]	82	4.173	4.173	1.663	4.488	8.566	2	0.7 – 31	0.3 – 27	220 - 320	16 - 273
Diller and Ely [31]	59	4.468	4.432	1.883	4.81	9.666	0	1.7 – 59	0.7 – 24	293 - 500	17 – 140.5
Michels et al. [37]	185	1.305	1.018	1.632	1.918	8.128	39	0.9 – 72	0.4 - 26.8	273 - 348	14 - 219
Padua et al. [38]	65	2.654	2.573	1.642	3.045	6.338	0	6 – 100	16.7 - 27	260 - 300	63 - 240
Overall	513	3.219	3.042	2.509	3.942	9.994	56	0.1 -172	0.0 - 27	219 - 500	14 - 273
Helium											
Gracki and Ross [39]	35	2.75	-2.75	1.924	3.341	-6.84	0	0.5 - 17	0.0	183 - 298	14 - 20
Nitrogen											
Overall (19 sources)	677	1.214	0.21	1.928	1.938	8.821	14	0.0 - 401	0.0 - 31	67 - 3273	5 - 348
Oxygen											
Overall (16 sources)	406	2.247	-0.502	3.142	3.178	-9.819	40	0.0 – 79	0.0 - 39	70 - 3273	6 - 444

Table 3. Compositions for Natural Gas and Multi-Component Systems (in Mole Fraction)

System	Source	CH ₄ 1	C ₂ H ₆ 2	C ₃ H ₈ 3	n-C ₄ H ₁₀ 4	i-C ₄ H ₁₀ 5	n-C ₅ H ₁₂ 6	n-C ₆ H ₁₄ 7	n-C ₇ H ₁₆ 8	CO ₂ 9	N ₂ 10	He 11	O ₂ 12
Tern4	[42]		0.3763	0.3901	0.2336								
Quar1	[42]	0.3655	0.2424	0.2695	0.1226								
Tern5	[43]	0.5285								0.2713	0.2002		
Tern6	[43]	0.2941								0.1953	0.5106		
Tern7	[43]	0.1758								0.5588	0.2654		
Tern8	[43]	0.3115								0.3456	0.3429		

Table 4. Viscosity Prediction Results and the Data Ranges for Natural Gases and Multi-Component Systems

System	Source	No of Points	AAD	Bias	Std.Dev	RMS	MaxDev	No of Points Dev> 10%	P [MPa]	D [mol.dm ⁻³]	T [K]	μ [μ Pa.s]
NG1	[40]	29	1.35	1.32	0.81	1.54	2.92	0	1.4 - 27.6	0.4 - 8.6	311 - 444	12.6 - 22.6
NG2	[40]	24	1.94	0.50	2.17	2.19	5.40	0	5.5 - 55.2	1.7 - 16.5	311 - 444	15.3 - 51.0
NG3	[40]	26	2.89	2.80	1.72	3.26	5.29	0	1.4 - 17.2	0.5 - 4.8	344 - 444	13.0 - 19.9
NG4	[40]	27	3.76	3.76	1.85	4.18	8.61	1	2.8 - 55.2	0.8 - 16.9	311 - 444	14.0 - 40.7
NG5	[27]	7	2.51	-2.51	0.45	2.55	-3.34	0	0.8 - 10.4	0.3 - 4.5	299 - 339	10.5 - 15.0
NG6	[27]	46	1.66	-1.47	1.78	2.30	-9.48	1	0.1 - 69.2	0.04 - 18.6	298 - 356	10.4 - 54.3
NG7	[27]	35	2.03	1.57	1.60	2.23	4.17	0	0.1 - 66.1	0.04 - 18.3	299 - 394	11.8 - 45.2
NG8	[27]	33	0.97	-0.82	0.79	1.13	-2.59	0	0.1 - 58.4	0.03 - 17.8	303 - 398	11.0 - 38.2
NG9	[41]	25	3.39	-1.61	3.96	4.19	9.25	3	0.2	0.04	289	9.6 - 12.9
Tern1	[42]	3	0.28	-0.19	0.44	0.40	-0.69	0	0.1	0.03 - 0.04	298 - 468	9.8 - 14.6
Tern2	[42]	3	0.22	-0.13	0.24	0.24	-0.34	0	0.1	0.03 - 0.04	298 - 468	9.6 - 14.4
Tern3	[42]	3	0.30	-0.07	0.40	0.33	-0.45	0	0.1	0.03 - 0.04	298 - 468	9.0 - 13.6
Tern4	[42]	3	0.17	0.10	0.21	0.19	0.30	0	0.1	0.03 - 0.04	298 - 468	8.3 - 12.8
Quart1	[42]	3	0.18	-0.07	0.26	0.22	-0.36	0	0.1	0.03 - 0.04	298 - 468	9.1 - 13.8
Tern5	[43]	3	0.50	-0.50	0.32	0.57	-0.82	0	0.1	0.03 - 0.04	298 - 473	14 - 21
Tern6	[43]	3	2.12	2.12	0.34	2.13	2.38	0	0.1	0.03 - 0.04	298 - 473	16 - 23
Tern7	[43]	3	2.71	2.71	0.39	2.73	2.99	0	0.1	0.03 - 0.04	298 - 473	15 - 23
Tern8	[43]	3	1.18	1.18	0.33	1.21	1.45	0	0.1	0.03 - 0.04	298 - 473	15 - 22
Overall		279	2.01	0.53	2.54	2.59	-9.48	5	0.1 - 69.2	0.03 - 18.6	289 - 473	8 - 54

* Densities of mixtures are calculated from the mixture density model by Lemmon and Jacobsen [1].

Table 5. Viscosity Prediction Results and the Data Ranges for Binary Systems

Source	No of Points	AAD	Bias	Std.Dev	RMS	MaxDev	No of Points Dev> 10%	P [MPa]	D [mol.dm ⁻³]	T [K]	μ [μ Pa.s]
C1 – C2											
Abe et al. [42]	15	0.43	-0.17	0.61	0.62	-1.46	0	0.1	298 - 468	9.6 - 15.5	0.26 - 0.75
Diller [44]	326	2.31	-0.20	3.10	3.11	9.91	10	1.5 - 34.9	100 - 300	9.9 - 736	0.35 - 0.69
C1 – C3											
Giddings [24]	282	1.39	1.12	1.74	2.07	8.81	0	0.1 - 55	311 - 411	8.9 - 125	0.22 - 0.79
Abe et al. [42]	15	0.35	0.27	0.30	0.39	0.65	0	0.1	298 - 468	8.7 - 15	0.28 - 0.78
Huang [45]	140	2.62	1.92	2.66	3.27	8.04	0	3.4 - 34.5	123 - 311	11 - 589	0.22 - 0.75
C1 – C4											
Kestin and Yata [46]	41	0.30	0.28	0.23	0.36	0.87	0	0.1 - 0.7	293 - 303	7.2 - 11	0.36 - 0.84
Abe et al. [42]	15	0.47	0.30	0.48	0.55	1.07	0	0.01	298 - 468	8 - 14	0.16 - 0.74
C1 – CO ₂											
Kestin and Yata [46]	48	4.45	-4.45	3.38	5.57	-8.86	0	0.1 - 2.57	293 - 303	11 - 15	0.14 - 0.67
DeWitt and Thodos [47]	132	6.21	-6.21	1.78	6.45	-9.92	7	3.4 - 69	323 - 474	14 - 86	0.2 - 0.8
Kestin and Ro [43]	25	5.33	-5.12	3.38	6.10	-8.6	0	0.1	298 - 473	13 - 23	0.2 - 0.7
C1 – N ₂											
Bzowski et al. [48]	26	2.98	2.98	0.73	3.07	5.32	0	0.1	200 - 3272	10 - 78	0.5
Diller [49]	276	4.28	-3.01	4.33	5.26	-9.97	61	1.6 - 33.6	100 - 300	8 - 173	0.3 - 0.7
Kestin and Ro [43]	25	2.15	2.14	1.11	2.40	3.36	0	0.1	298 - 473	12 - 25	0.2 - 0.8
C2 – C3											
Abe et al. [42]	17	0.62	0.40	0.59	0.70	1.17	0	0.1	298 - 468	8 - 14	0.34 - 0.86
C2 – C4											
Abe et al. [42]	15	0.40	0.29	0.43	0.51	1.30	0	0.1	298 - 468	7 - 14	0.19 - 0.84
C2 – CO ₂											
Diller et al. [50]	205	7.12	-5.62	4.85	7.38	-9.97	163	2.1 - 36.8	210 - 320	12 - 229	0.26 - 0.75
Diller and Ely [31]	148	4.49	-3.65	3.69	5.17	-9.92	55	1.7 - 61	319 - 500	12 - 100	0.3 - 0.7
Abe et al. [51]	10	0.60	-0.57	0.46	0.72	-1.47	0	0.1	298 - 468	12 - 20	0.3 - 0.6
C2 – N ₂											
Bzowski et al. [48]	21	6.21	6.21	0.16	6.21	6.46	0	0.1	250 - 1273	11 - 38	0.5
Abe et al. [51]	10	6.16	6.16	0.56	6.18	6.93	0	0.1	298 - 468	12 - 21	0.3 - 0.7
C3 – C4											
Abe et al. [42]	19	0.65	0.65	0.46	0.79	1.82	0	0.1	298 - 468	7 - 12	0.22 - 0.8
C3 – CO ₂											
Abe et al. [51]	10	1.64	1.64	0.32	1.67	2.17	0	0.1	298 - 468	10 - 19	0.3 - 0.7

Source	No of Points	AAD	Bias	Std.Dev	RMS	MaxDev	No of Points Dev> 10%	P [MPa]	D [mol.dm ⁻³]	T [K]	μ [μ Pa.s]
C3 – N ₂											
Abe et al. [51]	10	7.71	7.71	0.56	7.72	8.53	0	0.1	298 - 468	11 - 19	0.3 - 0.6
C4 – CO ₂											
Abe et al. [51]	12	3.20	3.20	0.49	3.23	3.95	0	0.1	298 - 468	10 - 17	0.3 – 0.6
C4 – N ₂											
Abe et al. [51]	9	7.90	7.90	0.79	7.94	9.03	0	0.1	298 - 468	14 - 20	0.1 – 0.5
C7 – N ₂											
Carmichael and Sage [52]	2	5.0	5.0	1.33	5.09	5.94	0	0.01 – 0.02	344 - 344	10 – 16	0.15 - 0.48
CO ₂ – N ₂											
Bzowski et al. [48]	25	3.30	-3.30	0.91	3.41	-4.01	0	0.1	250 - 3272	14 – 93	0.5
Kestin and Ro [43]	28	2.43	-2.43	0.72	2.53	-3.95	0	0.1	298 - 873	15 - 38	0.2 - 0.8

Table 6. Physical Properties for NG Components

Property	Unit	Methane 1	Ethane 2	Propane 3	n-Butane 4	i-Butane 5	Pentane 6	Hexane 7	Heptane 8	CO2 9	Nitrogen 10	Helium 11	Oxygen 12
M.W.		16.0428	30.07	44.0956	58.1222	58.1222	72.1488	86.1754	100.202	44.0098	28.0135	4.0026	31.9988
Dc	mol.dm ⁻³	10.139	6.87	5.0	3.92	3.86	3.215578	2.70588	2.31532	10.62491	11.1839	17.399	13.63
Pc	MPa	4.5992	4.8718	4.24766	3.796	3.64	3.3665	3.0181	2.727	7.3773	3.3958	0.22746	5.043
Tc	K	190.564	305.33	369.85	425.16	407.85	469.7	507.82	540.13	304.1282	126.192	5.1953	154.581
A.F.		0.01142	0.0993	0.15243	0.199586	0.18534	0.251	0.297	0.348	0.22394	0.037	-0.382	0.022